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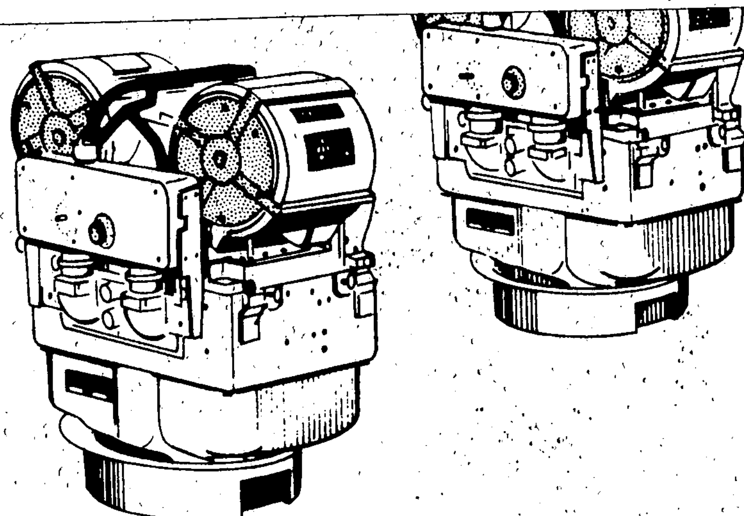
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER, HOUSTON, TEXAS



CAMERA CALIBRATION LABORATORY CAPABILITIES

NOVEMBER 1972

EARTH OBSERVATIONS DIVISION

LEC

LOCKHEED ELECTRONICS CO., INC.
A Subsidiary of Lockheed Aircraft Corporation
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EOD FACILITIES MANUAL

CAMERA CALIBRATION LABORATORY CAPABILITIES

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INTRODUCTION

The Earth Observations Program at the Manned Spacecraft Center requires photographic systems that perform with exceptional precision. The cameras used aboard aircraft and spacecraft do more than simply take pictures; they record precise spectral and spatial information for use in earth resources applications.

These photographic systems may be divided into three general categories: metric mapping cameras, multispectral camera arrays which record up to six images of the same scene in different wavelengths, and boresight cameras which record images for correlation with data recorded by radiometers or other types of remote sensors. A variety of lenses, film types, and filters can be combined with these basic systems to adapt them for specific applications. The work done in the Camera Calibration Laboratory assures that the photographic systems used by the Manned Spacecraft Center (MSC) for earth resources, space, or other applications will record the desired information with optimum spatial and spectral fidelity. The laboratory contains equipment (fig. 1) to measure the exact performance characteristics of camera systems.

The ultra-precise optical measurement devices are so sensitive that they must be mounted on shock-isolated blocks of polished granite weighing up to 10 tons. Some of the heavy assemblies ride on air bearings, making it possible to change their positions with little effort to facilitate very fine adjustments of the equipment.

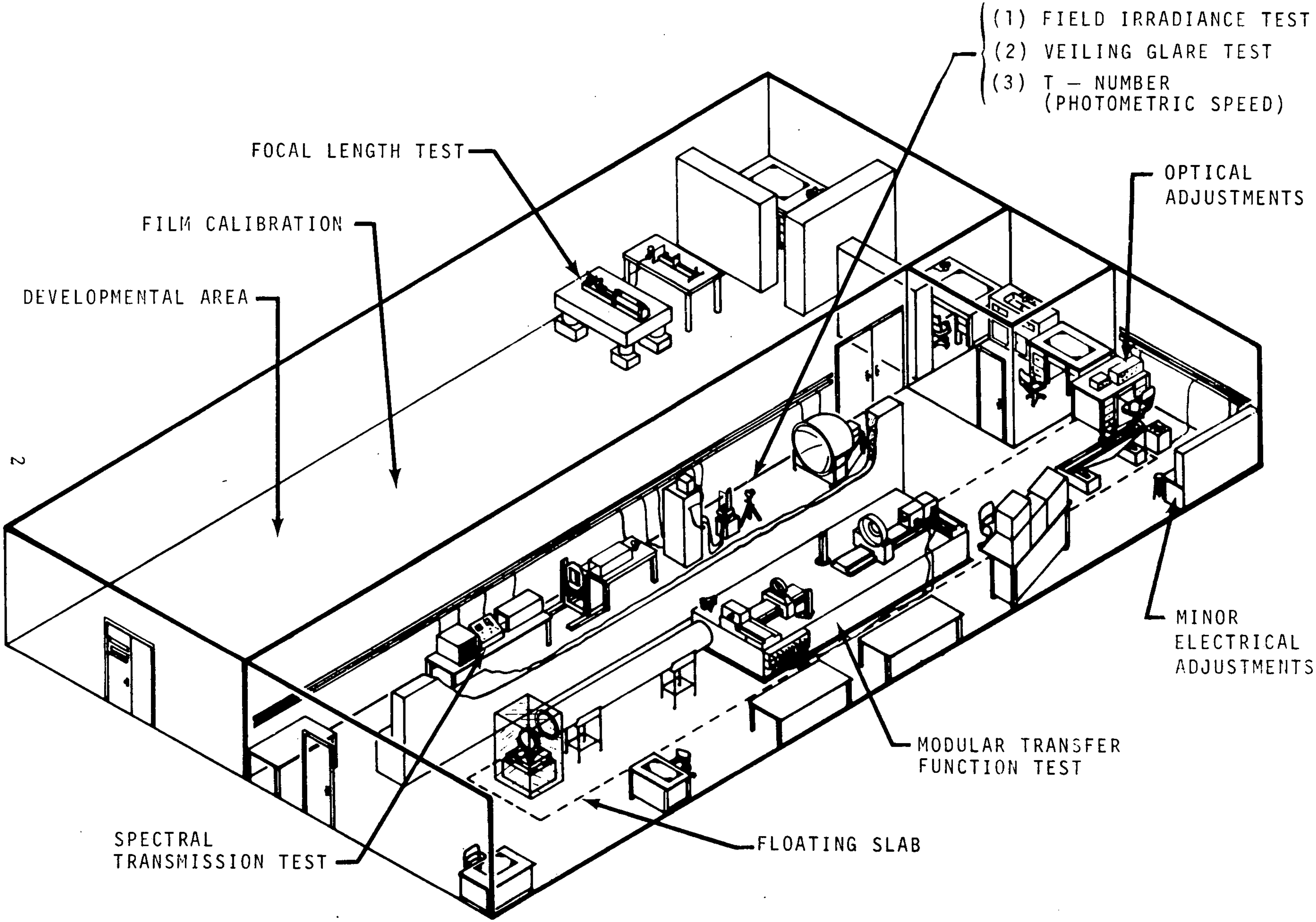


Figure 1. — Test equipment in the camera calibration laboratory.

Types of tests performed with this equipment are:

- Modulation transfer function
- Field irradiance
- Veiling glare
- T-number
- Shutter speed
- Spectral transmission
- Focal length

These tests are performed as required on any of the cameras used in the Earth Observations Program. Even new cameras of the same model and manufacture are calibrated to detect individual variations that affect performance.

Calibration covers all camera system components, and the resulting data can be used by image analysts to compensate for optical perturbations that occur with various operational configurations. Photographic data is recorded as film emulsion densities that vary with the intensity of radiations reflected from the field of view. These densities can be measured electronically and assigned digital values. The density values, with calibration correction factors, can then be used to reconstruct the corrected image as a display on the cathode ray tube of an electronic data analysis station.

1.0 MODULATION TRANSFER FUNCTION TEST

In the modulation transfer function test used at MSC, the lens is treated as if it were a light filter in an optical system, assuming the image motion allows it. This means that instead of having to depend on semisubjective interpretations, we can measure the filtering action by means of calibrated instruments. A known, well controlled signal is passed through the test lens, and the resultant output is compared to the original.

The modulation transfer function (MTF) test tells us more about the performance of a lens than the conventional three bar line pattern tests. For example, the USAF (1951) Resolution Test Patterns use line patterns which become finer and closer together. In this USAF test the operator views the image of the pattern formed by the test lens. The standard is the finest lines that remain individually visible. The result is expressed in lines per millimeter. This type of test tells us something about the lens quality, but its parameters are not rigorous, and the results are subjective. The interpretations of individual operators may vary by as much as 30 percent. The MTF test provides a more accurate discription of lens performance.

The major components of the MTF test are arranged as shown in figure 2, modulation transfer function test equipment. These pieces of test equipment are:

- Object Generator
- Collimator

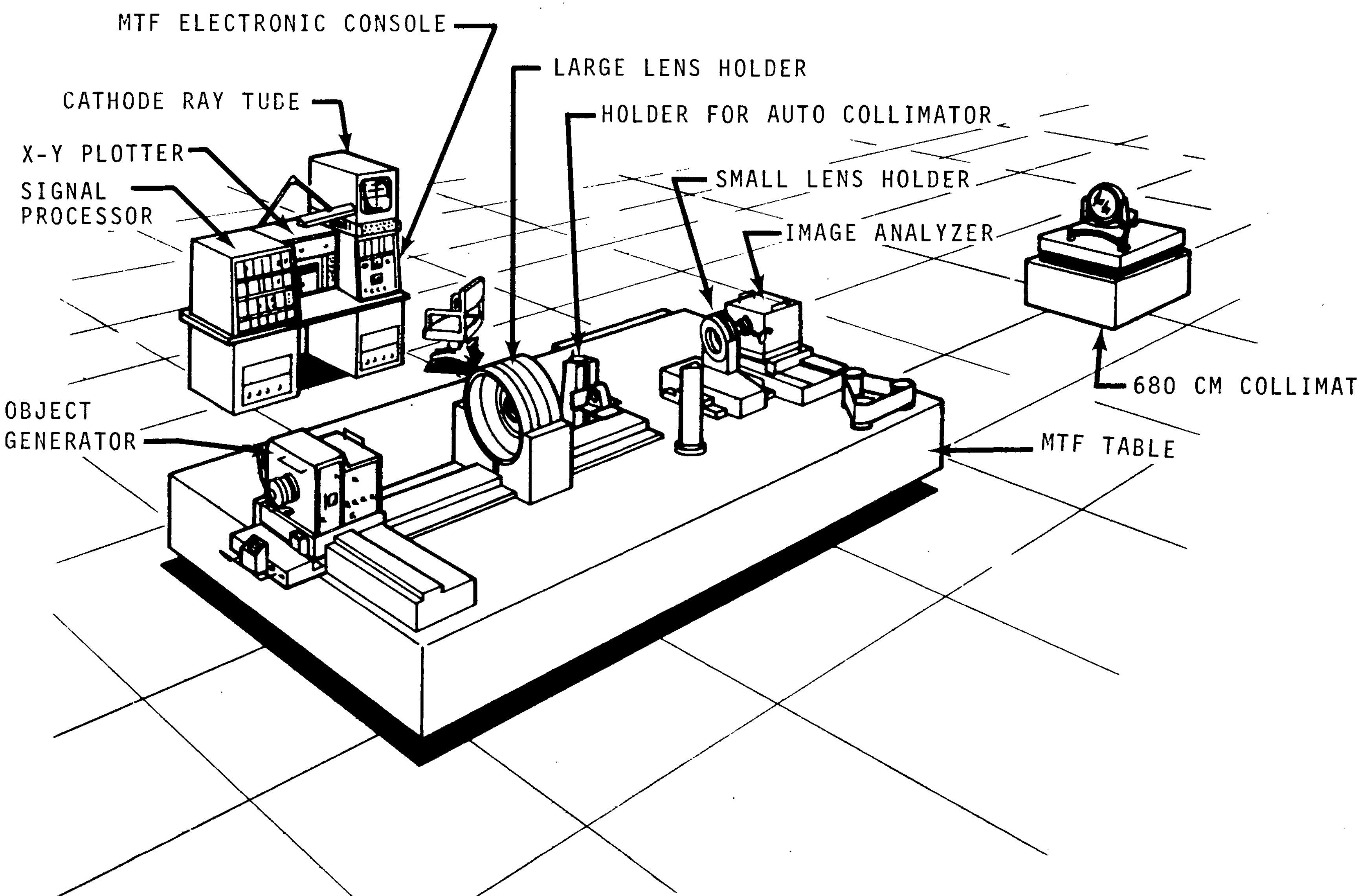


Figure 2. — Modulation transfer function test equipment.

- Lens Holders
- Image Analyzer
- Signal Processor
- Cathode Ray Tube
- X-Y Plotter

In this test arrangement, lenses of up to 50 inches focal length may be tested either in white light or with selectable filters. They may be tested over a spatial frequency of zero to 400 cycles per millimeter. NOTE: We are dealing with cycles in space, not in time.

The object generator (figure 2) presents a continuously variable wave target, with spatial frequency from zero to 150 cycles per millimeter. On the other side of the lens the image analyzer receives this variable target, measures its degradation, and sends out a signal that is processed by the X-Y plotter and displayed on the CRT screen. The cycles per millimeter, modulator percentage, and phase angle are plotted. A typical modulation transfer function curve (figure 3) shows that at zero cycles per millimeter the modulation is 1.0; that is, the lens transmitted 100 percent of the information presented to it at zero cycles per millimeter. As the spatial frequency goes up and the pattern becomes finer, the lens passes less information and the contrast decreases. NOTE: Higher spatial frequencies are attainable, but 150 cycles per millimeter is the normal experimental figure used for recording.

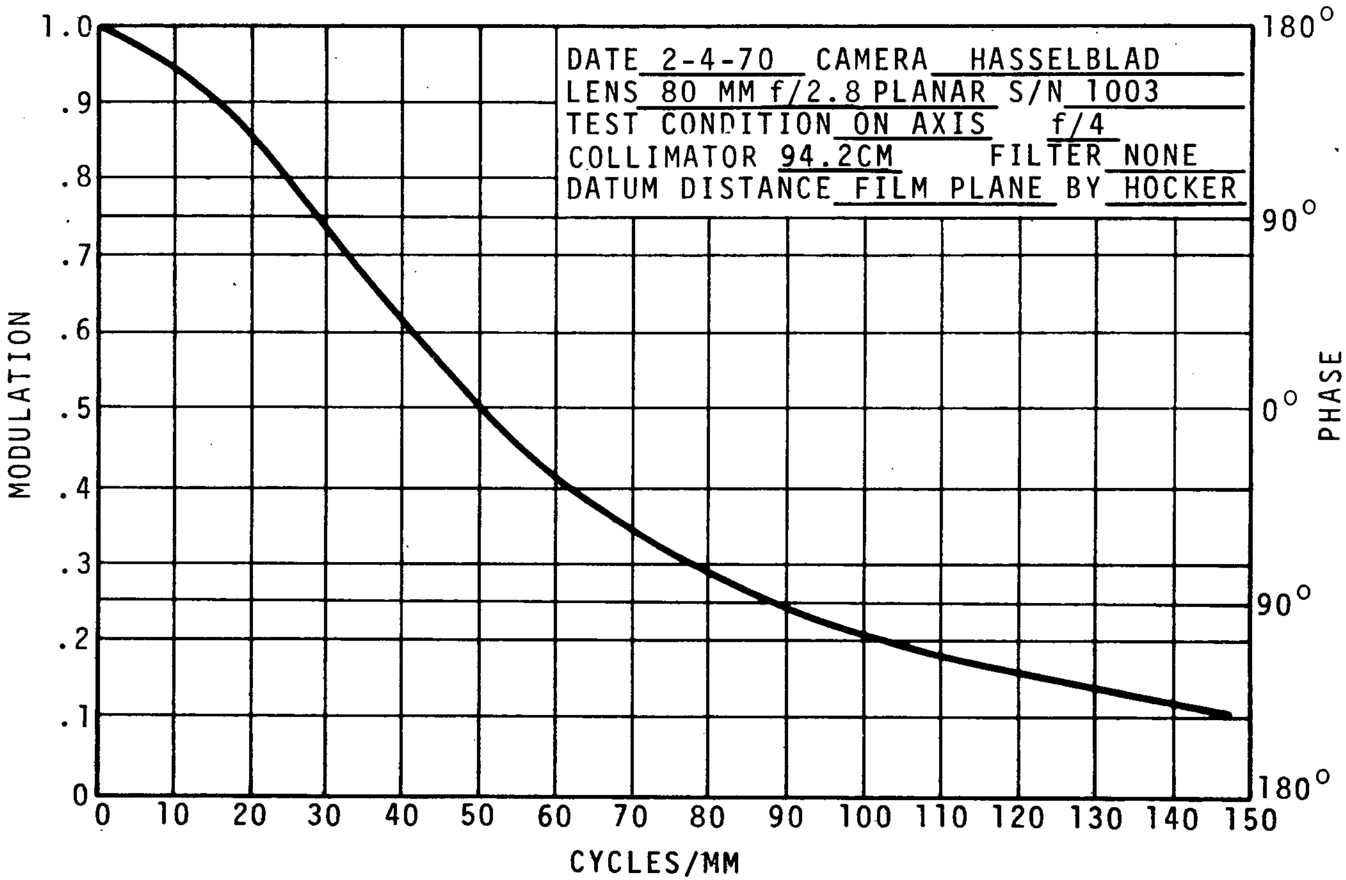


Figure 3. — Typical modulation transfer function curve.

The modulation transfer function test is usually conducted in these modes:

a. On axis, at best focus and also in the normal film plane.

b. Off axis, plus and minus 50 millimicrons from the film plane.

c. Off axis, in the film plane, sagittal and tangential curves at 1/4, 1/2, and 3/4 of the diagonal field.

NOTE: Steps a, b, and c are performed at infinite conjugate, using the camera apertures that are generally used on mission: f/5.6, f/8, and f/11.

Here, in figure 4, are modulation transfer function curves made with the Hasselblad 80 mm PLANAR lens at f/2.8, f/4, f/5.6, f/8, and f/11. The lens performance quality increased as it was stopped down. The curves of figure 4 also show that at 55 cycles per millimeter the lens performance is nearly 2-1/2 times better at f/5.6 than at f/2.8. We would conclude that under the given conditions, for this particular test lens the shutter should be adjusted to permit photography at f/5.6.

Figure 5, (lens diagnosis by means of modulation transfer function curves), shows how the modulation transfer function curve can serve as a diagnostic tool. The lens used for these curves was about to be mated with a camera that contained a reseau plate. In this case the reseau was a glass plate with small squares of fine lines, used for photographing the stars. In this figure, the lower curve is for the lens performance at the film plane. However, the upper curve is

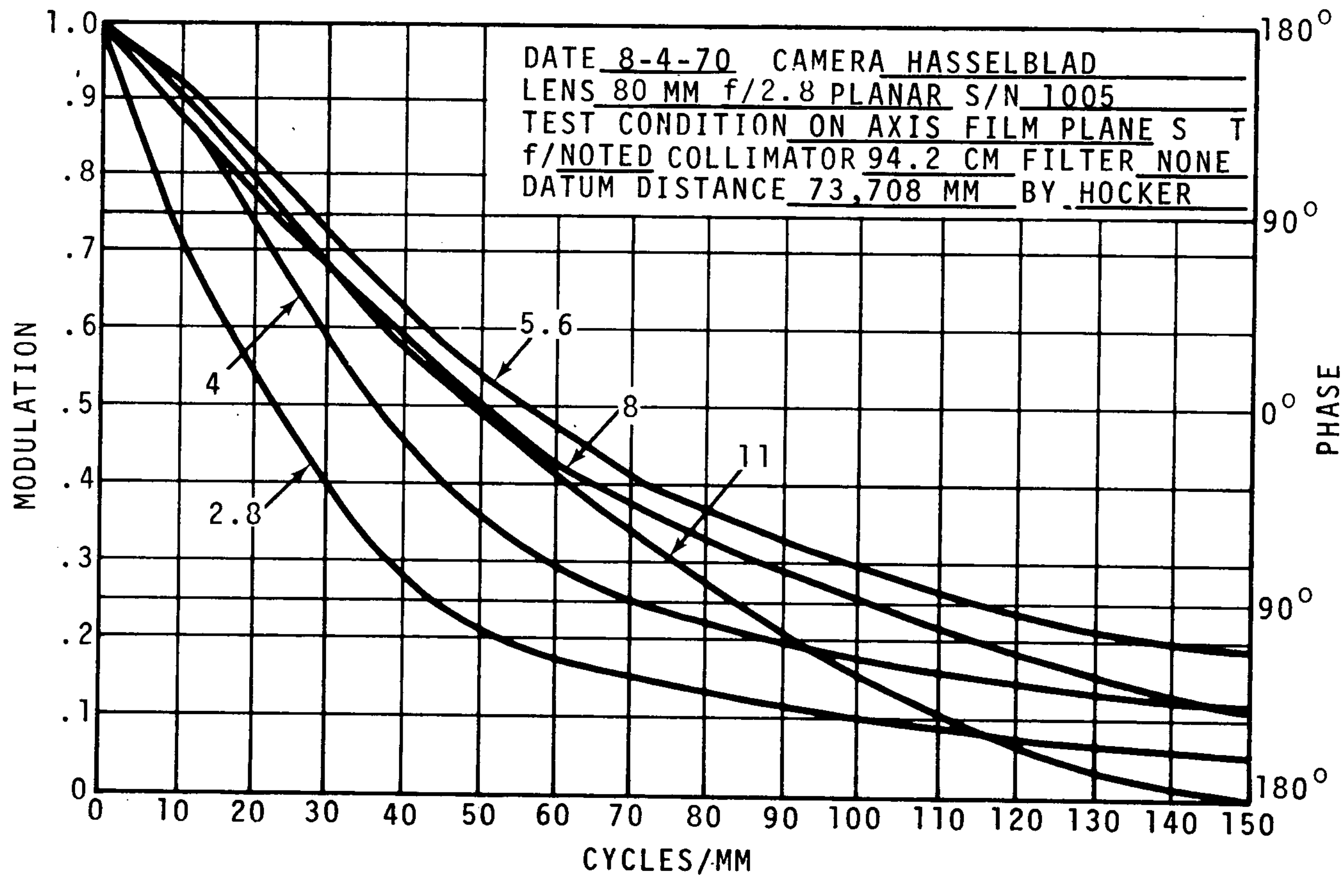


Figure 4. — Test lens modulation transfer function curves.

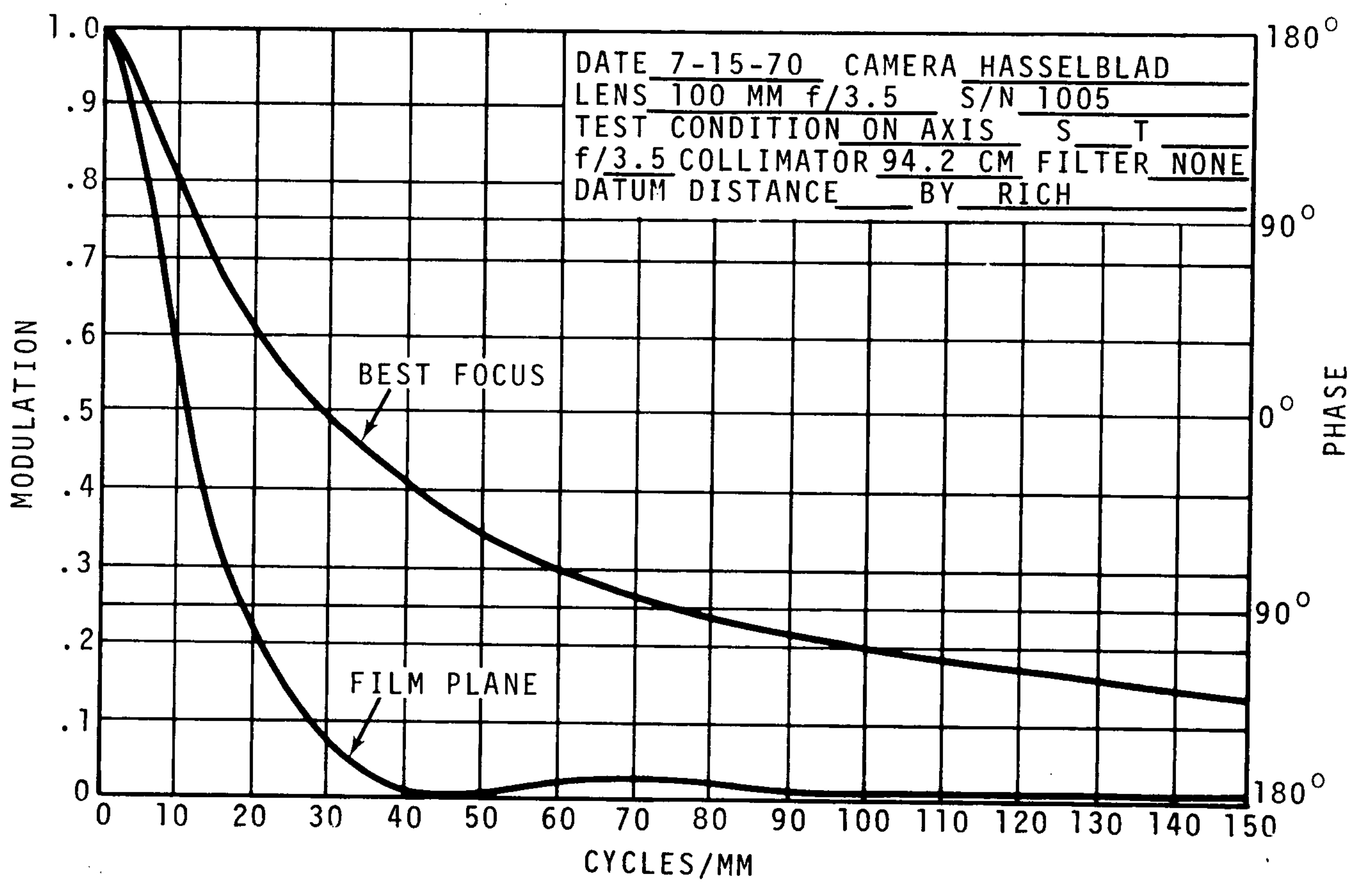


Figure 5. — Lens diagnosis by means of modulation transfer function curves.

in the plane of best performance. Adding the glass plate in the camera has lengthened the optical path enough to degrade the lens performance to a practically useless level. The curves found and explained the trouble.

It is possible to compare the resolution performance of two or more similar lenses by superimposing their modulation transfer function curves (produced under identical conditions) one atop another. That way it becomes obvious which lens is best for a particular purpose. The relative modulation transfer functions at identical spatial frequencies will provide numerical values for the comparison.

2.0 FIELD IRRADIANCE TEST

The field irradiance test measures the uniformity of illumination through a lens at its film plane. This also measures vignetting characteristics, which arise when some part of the camera or lens housing cuts off part of the light reaching the film plane.

The major components of the field irradiance test are arranged as shown in figure 6, field irradiance test equipment. These pieces of test equipment are:

- Uniform Luminance Hemisphere (Light Source)
- Camera Under Test
- Automatic Scanner
- Scanner Electronics
- Photomultiplier
- Photometer

B

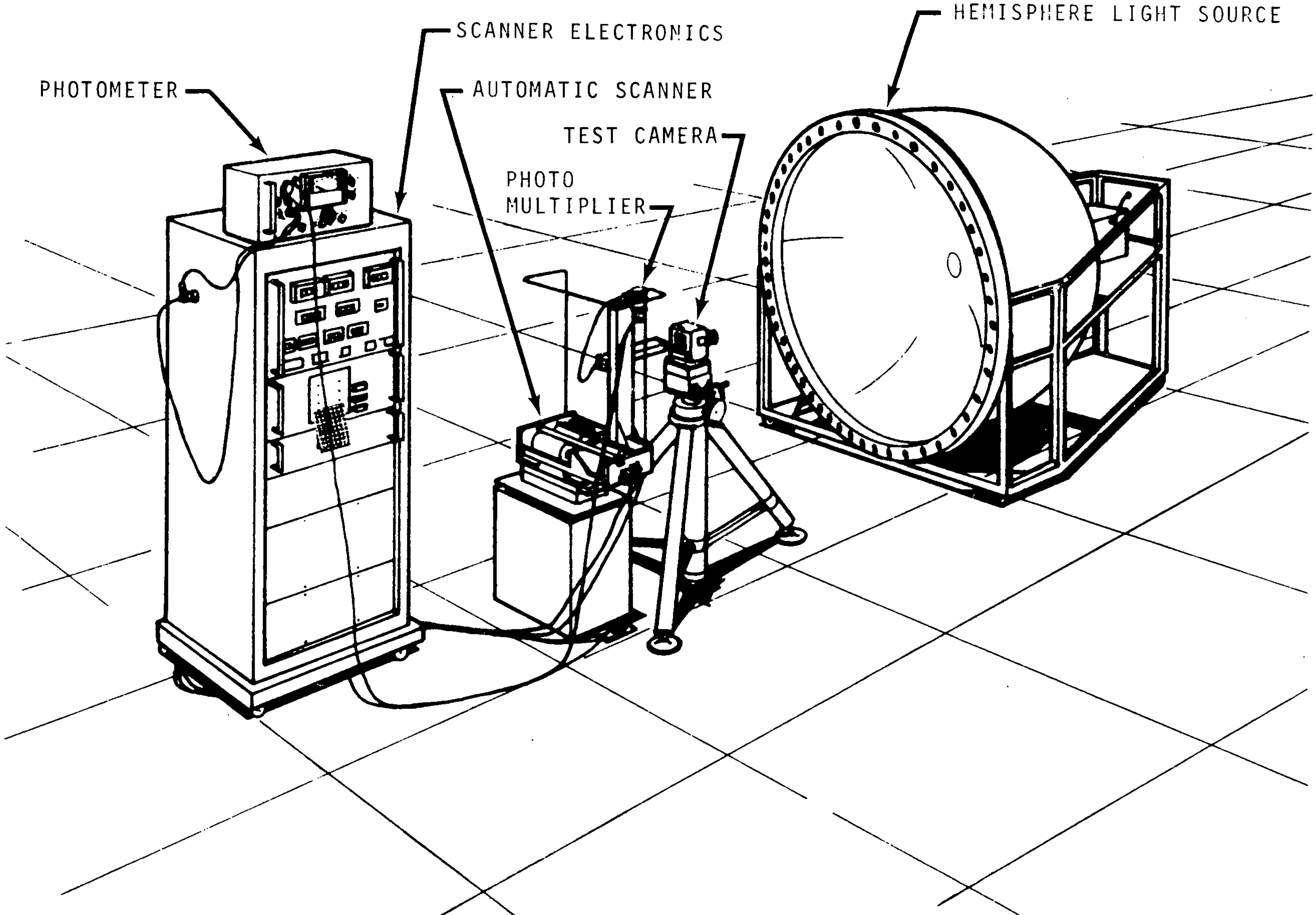


Figure 6. — Field irradiance test equipment.

The uniform luminance hemisphere light source is covered internally with special paint that ensures even and diffused reflections. At the center of the hemisphere is an opening into which may be fitted various apertures. For the field irradiance test, the opening at the center of the hemisphere is covered by the same material as the rest of the hemisphere. Therefore, the camera faces a uniform bright diffusing surface.

During the field irradiance test the uniform luminance hemisphere is illuminated at about 400 foot Lamberts, and adjusted to a uniformity of 1-1/2 percent. The fiber optic probe, equipped with a cosine head for use with the photometer, is normalized at the precise center of the film format. The illumination is recorded versus position. From these readings field irradiance plots are produced.

The illumination uniformity of a camera with and without an antivignetting filter is compared in Figure 7, (Field irradiance plots with and without antivignetting filter). Plot contours are generally drawn for each 5 percent change of intensity.

3.0 VEILING GLARE TEST

The veiling glare test measures the overlap of light into the dark areas of the object, as recorded by the lens. This overlap is caused by unwanted stray reflections or scattered light from the lens elements or from parts of the lens barrel. This light decreases the contrast of the primary image and thus causes image degradation.

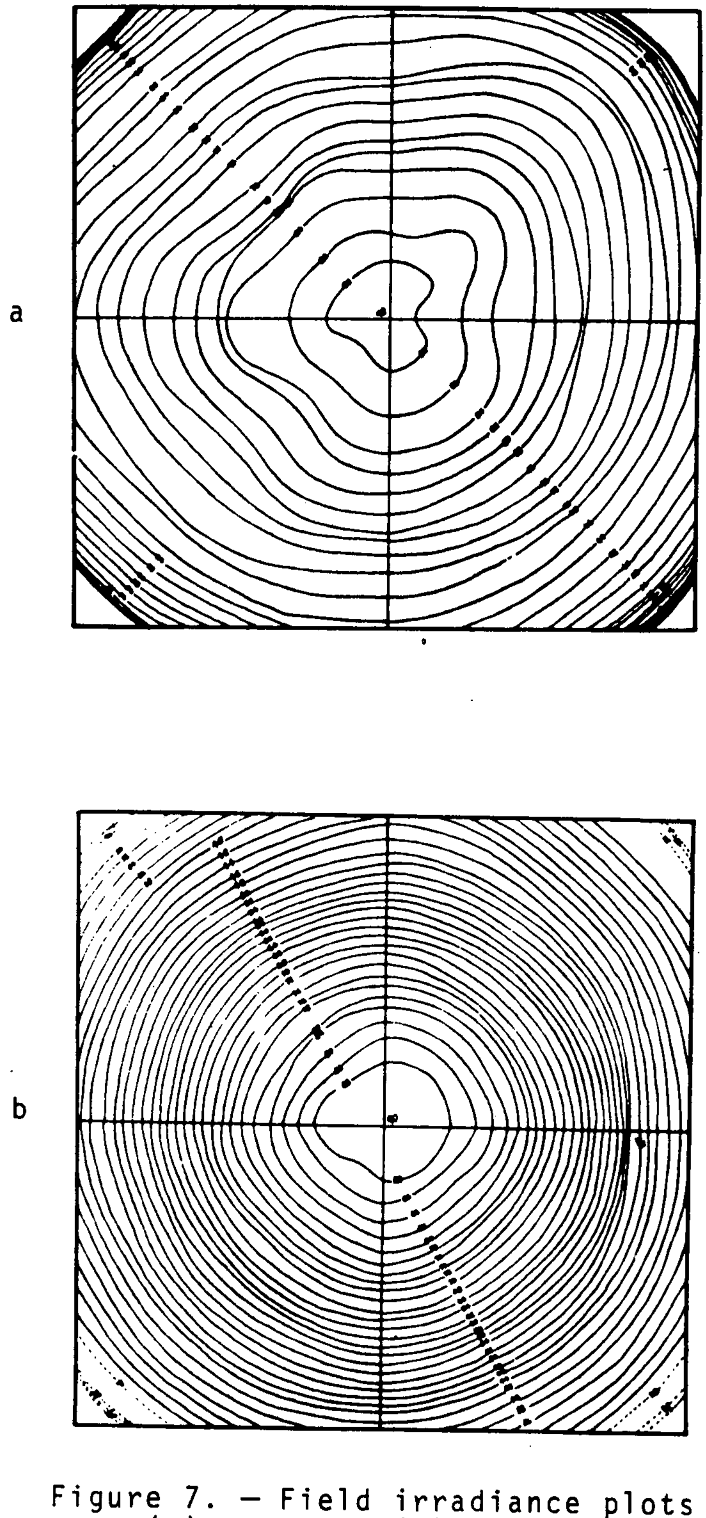


Figure 7. — Field irradiance plots (a) with and (b) without antivignetting filter.

The test equipment for the veiling glare test is the same as for the field irradiance test and similary arranged (figure 6), except that a black patch can be introduced at the center of the uniform luminance hemisphere during part of the test. This black patch is actually a black hole to ensure a 100 percent absorption condition (figure 8, uniform luminance hemisphere with black aperture). The center of the uniform luminance hemisphere is projected by the test lens onto a small sensor that feeds into a photomultiplier. The signal from the photomultiplier is then processed by the electronic unit to show 100 percent on a display meter or chart. Pulling a lever on the equipment will cause the black hole to be uncovered at the center of the hemisphere. Ideally, the lens should picture only the black hole of zero reflectance onto the sensor and thus cause the meter to fall to a zero reading. The actual reading recorded by the meter thus becomes a measure of the veiling glare.

4.0 T-NUMBER TEST

The speed of a lens expressed in terms of "f" number value creates several uncertainties. The "f" number is a geometrical quantity expressing the ratio of the lens focal length to its aperture. Because of factory variations in the focal length and in the iris mechanism, two similar lenses with identical "f" numbers may not have the same effective speed. The presence of anti-reflection coatings, variations in the diaphragm shape (pentagonal, scalloped, etc.), and similar differences make it desirable to have a photometric rather than a geometric speed number. Then, the shape of the aperture, the actual focal length of the lens, the lens

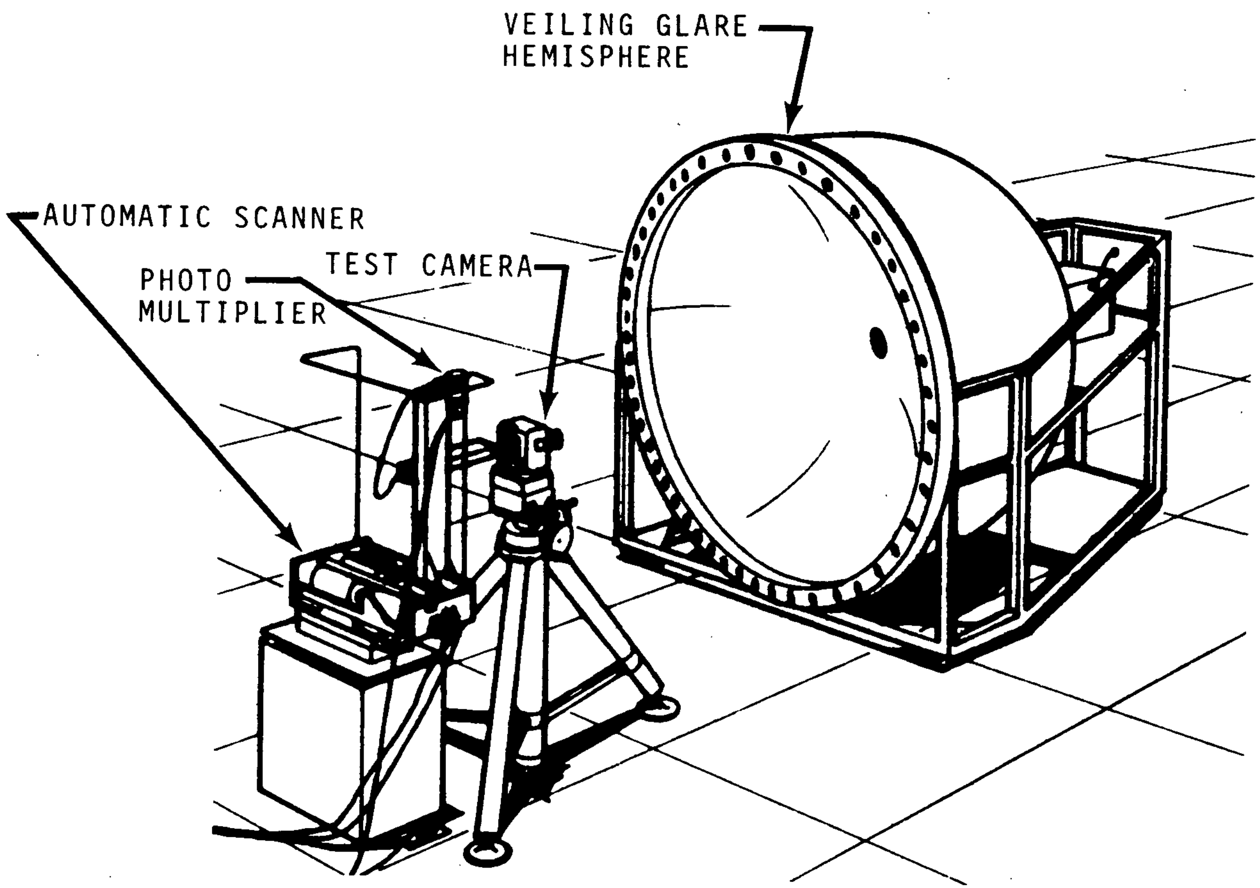


Figure 8. — Uniform luminance hemisphere with black aperture.

transmittance, internally reflected stray light, and all such variables will be accounted for, automatically.

The photometric speed number is called the "T" number. This "T" number is defined as "the f-number of an open circular hole that would give the same central-image illumination as the actual lens at the specified stop opening."

Hence, for a lens with a circular aperture

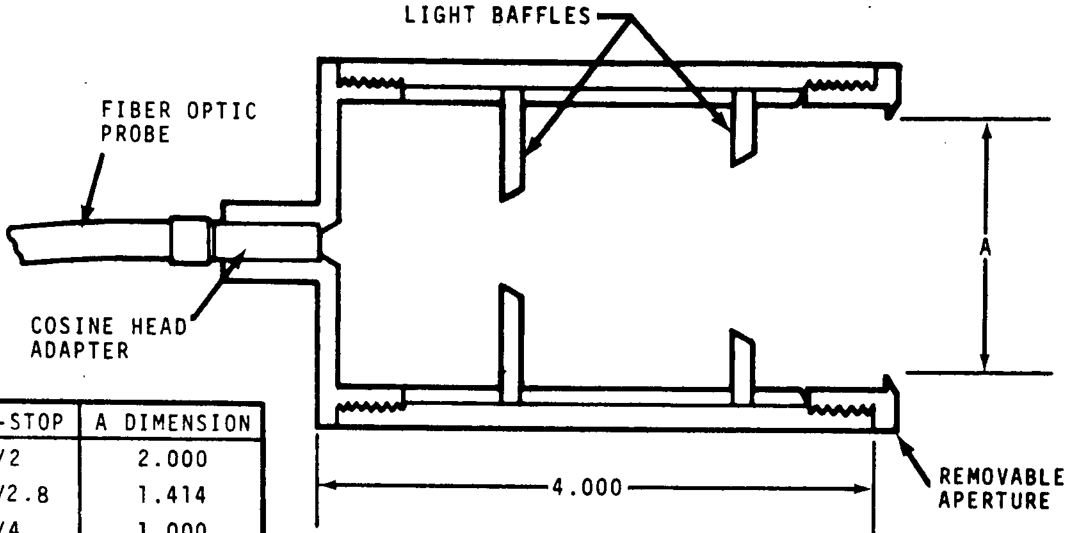
$$\text{T number} = \frac{\text{f number}}{\sqrt{\tau}}$$

where τ is the photometric transmittance of the lens system (= emerging flux divided by entering flux).

Figure 9 shows a T-stop calibrator in sectional view. Dimension "A" is very carefully machined to be exactly 2.000 inches. The aperture-to-probe distance is also maintained at 4.000 inches. This condition produces a T-number value of 2.

For other T-number values the aperture cap at "A" is removed and a different cap substituted. Other caps suitably machined to provide T-stops of 2.8, 4, 5.6, 8, or 11 are all so made that the aperture-to-probe distance is maintained in each case at exactly 4.000 inches. The figure shows the different apertures required in each case.

The test uses the uniform luminance hemisphere as the source. The T-stop calibrator and the camera under test are mounted side by side; the fiber optic probe (with cosine head) being switched from the calibrator to the camera and back for each



T-STOP	A DIMENSION
T/2	2.000
T/2.8	1.414
T/4	1.000
T/5.6	.707
T/8	.500
T/11	.353

Typical discrepancy between a camera's marked f/Numbers and the computed T/Numbers. (Camera without filter.)

Marked f/Number	Computed T/Number
2.8	3.23
4	4.70
5.6	6.67
8	9.46

Figure 9. — T-Stop calibrator.

f-number being tested. The T-number aperture corresponding to the f-number set on the camera lens is used each time. The output of the fiberoptic probe is fed to a photometer, normalized for the calibrator, and recorded for the lens. The ratio of the lens to calibrator readings gives the "photometric transmittance" in the equation.

5.0 SHUTTER SPEED TEST

Considering that photographic exposure is equal to light intensity times the time of exposure, it is seen that the accurate measurement of the shutter action is as important as accurate T-number and lens transmission measurements.

The shutter speed test is conducted in accordance with requirements of PH3.4 1959 of the American National Standards Institute (ANSI). The major equipment components of the test are arranged as shown in figure 10, shutter speed test equipment. These pieces of equipment are:

- Uniform Luminance Hemisphere
- Camera Under Test
- Light Detector
- Oscilloscope
- Function Generator

The shutter speed test proceeds as follows:

a. Light from the uniform luminance hemisphere is directed through the operating shutter of the camera to the photodiode detector.

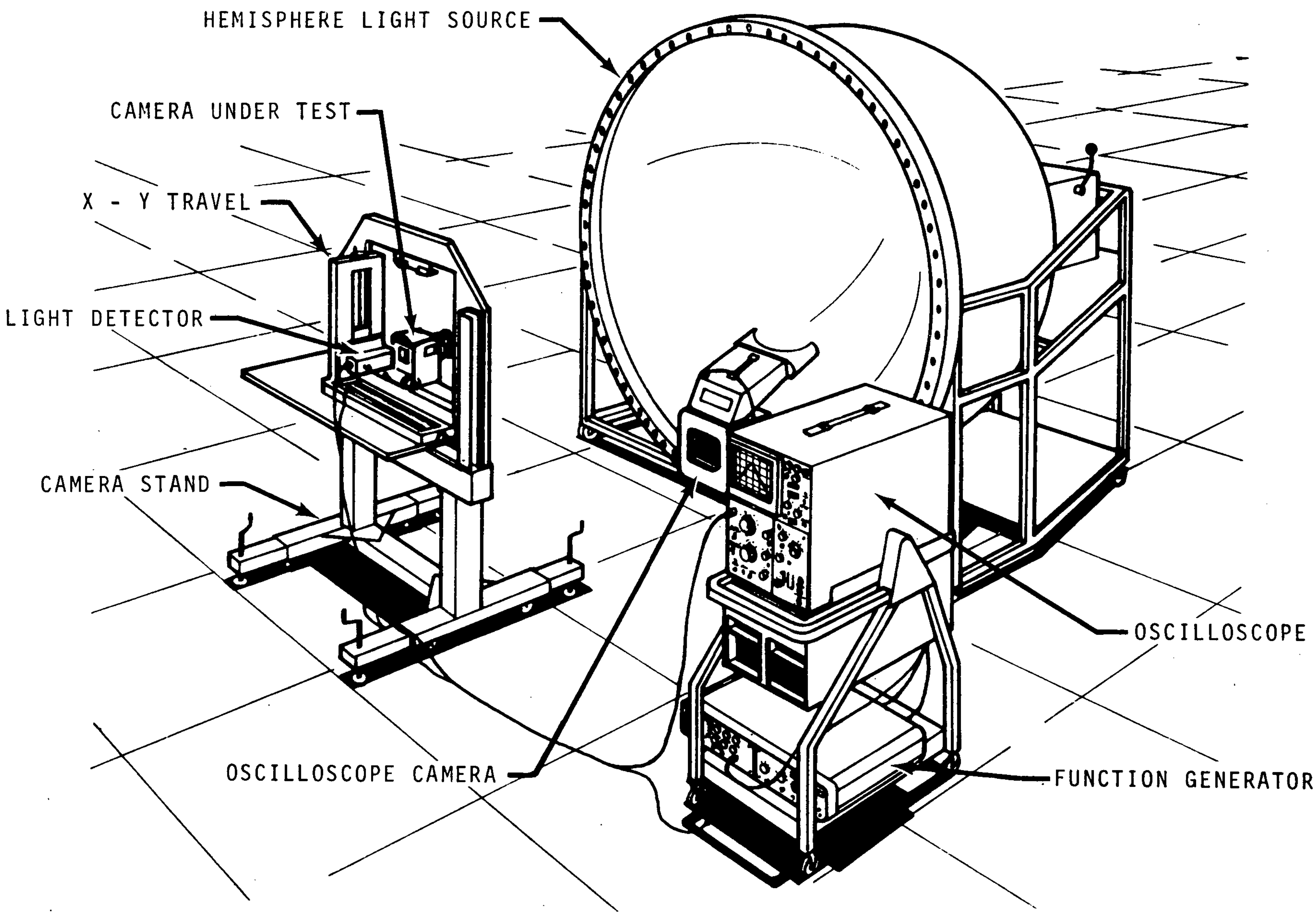


Figure 10. – Shutter speed test equipment.

b. The photodiode detector output is transmitted to the vertical deflection plates of the oscilloscope.

NOTE: Timing marks are provided by the precision square wave generator whose output is transmitted to the oscilloscope.

Figure 11 is a representation of a stylized oscilloscope trace of a shutter action in the shutter speed test. Three values can be derived from the oscilloscope record of the shutter speed test:

a. Total shutter open time (T_o). This also measures the motion stopping ability of the shutter.

b. Effective shutter open time (T_e). This is important to the photometrist.

c. The efficiency of the shutter (E).

The sample calculation included on figure 11 is typical. The symbols mean the following:

T_n – Nominal (marked) speed

f – Number of dots per second

T_o – Total (motion stopping) speed

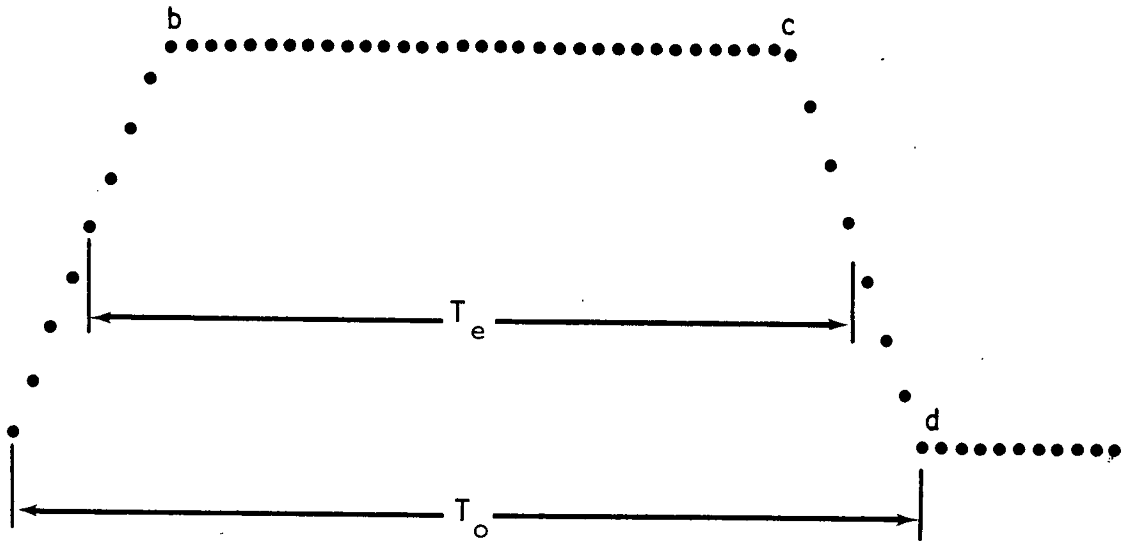
T_e – Effective (exposure) speed (half power point)

N_{ab} – Number of time intervals from a to b

E – Efficiency

6.0 SPECTRAL TRANSMISSION TEST

Lenses and filters alter the color balance of a scene as recorded by transmitting nonuniformly (or cutting out)



$$T_n = \frac{1}{125} \text{ sec}$$

$$f = 5 \text{ KHz}$$

$$T_o = \frac{Nad}{f} = \frac{47}{5,000} = 0.0094 = \frac{1}{106} \text{ sec}$$

$$T_e = \frac{\frac{Nab}{2} + Nbc + \frac{Ncd}{2}}{f} = \frac{\frac{8}{2} + 32 + \frac{7}{2}}{5,000} = 0.0079 - \frac{1}{127} \text{ sec}$$

$$E = \frac{To}{Te} = \frac{106}{127} = 83.5\%$$

Figure 11. — Stylized oscilloscope trace for shutter speed test.

different wavelengths of light coming from the object. The spectral transmission test measures the absolute spectral transmission of a lens, or of a lens and filter combination, across the spectral range of interest.

The major components of the test equipment are arranged as shown in figure 12. These pieces of equipment are:

- Uniform Luminance Source
- Camera Under Test
- Monochrometer
- Photomultiplier
- Photometer
- Strip Chart Recorder

The spectral transmission test proceeds in the following way.

a. Without the lens, a lamp calibration curve is plotted (see view A, figure 13, spectral transmission test graphs).

b. The lens under test is inserted into the optical path close to the spectrometer.

NOTE: The lens aperture must be larger than the f/8.6 spectrometer cone.

c. With the lens in place, another curve is plotted (see view B, figure 13).

The ratio between the first and the second curves shows the spectral transmission effect of the lens under test.

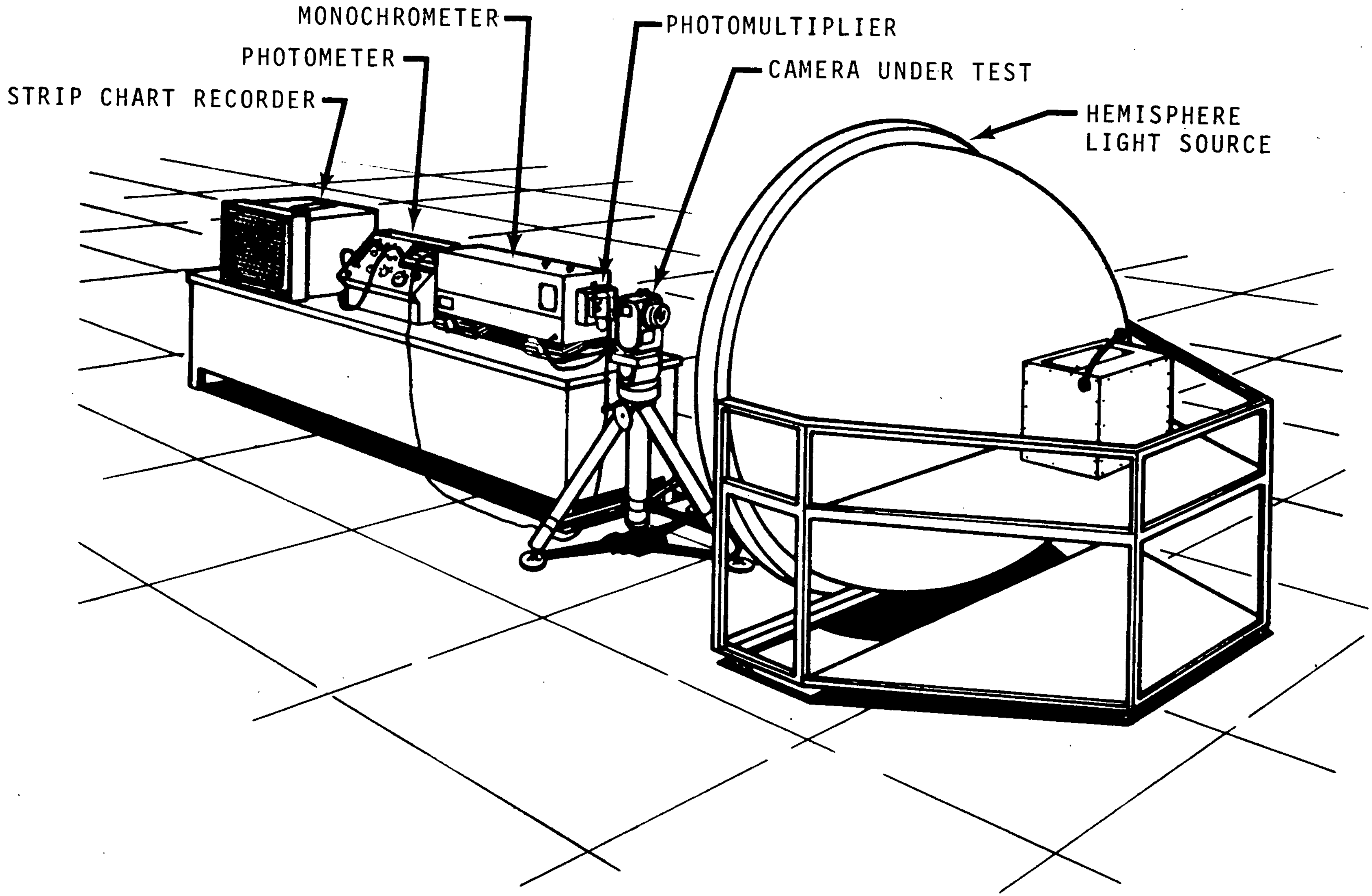


Figure 12. – Spectral transmission test equipment.

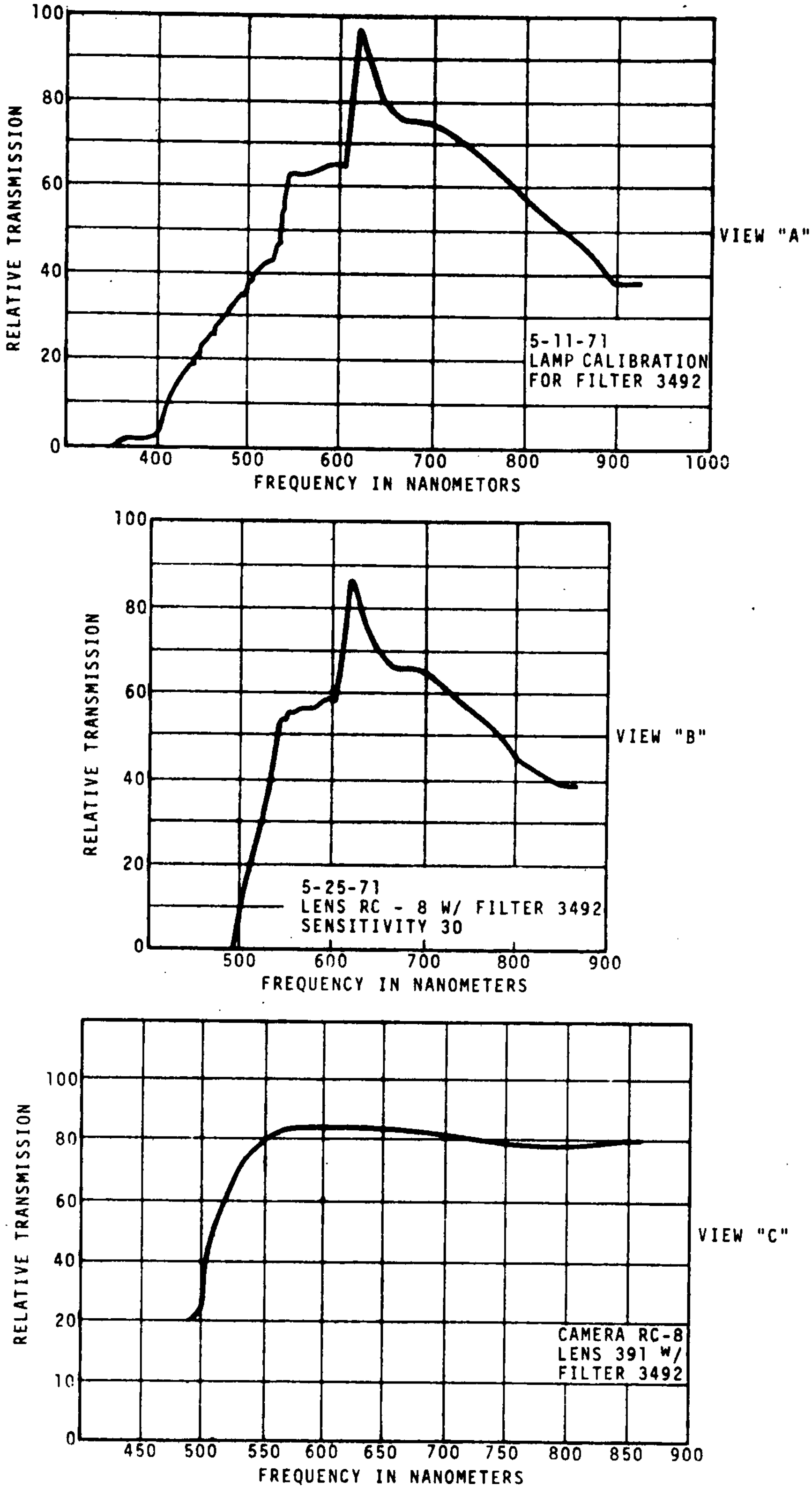


Figure 13. — Spectral transmission test graphs.

By dividing the lamp calibration curve by the lens curve, the absolute spectral transmission of the lens is obtained, as shown in view C.

7.0 FOCAL LENGTH TEST

Accurate determination of the focal length is required to obtain scale data from the film, and for use in other tests.

The major components of the focal length test are shown in figure 14, focal length test equipment. These pieces of equipment are:

- Lens Under Test
- Optical Bench
- Nodal Slide
- Light Source
- Collimator
- Measuring Microscope
- Target

The lens under test is mounted on the nodal slide. The nodal slide can rotate and translate the lens. When the lens is rotated around its rear nodal point, the image viewed by the microscope remains stationary. The effective focal length is the distance from the axis of rotation to the focal plane.

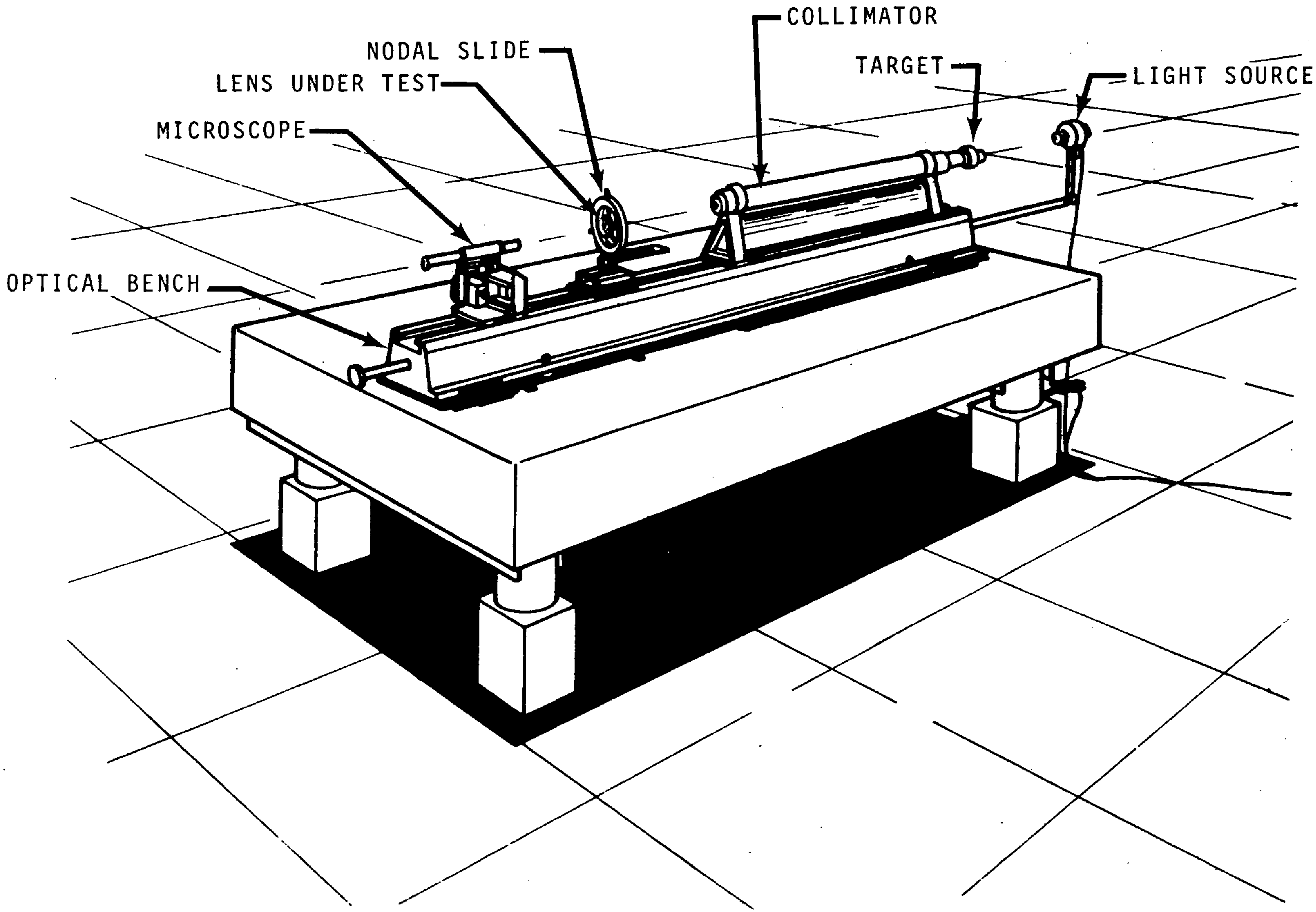


Figure 14. – Focal length test equipment.

CONCLUSION

The NASA/MSC Camera Calibration Laboratory verifies the manufacturers' specifications and selects and calibrates cameras best suited for particular NASA earth resources, space, and other scientific and technological missions. To ensure optimum information-yielding energy distribution across the focal plane it uses its equipment to select special purpose lenses, measures the modulation transfer functions of optical systems, and adjusts and calibrates shutter speed. By matching selected lenses and defining the correct exposure settings for specific cameras it minimizes radiometric distortion, thus providing an accurate basis for photometric interpretation of imagery.

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